How high liquid marble can be fabricated?

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Abstract

Cubic liquid marbles (LMs) with heights up to 5.0 mm can be fabricated by using square-shaped PET plates and water. By changing the shape of the LM from cube to pyramid to reduce the internal liquid volume, LMs with heights up to 7.9 mm can be fabricated. Furthermore, the introduction of a particle-stabilized bubble into the LM led to formation of the LM with heights up to 9.8 mm, which was > 3 times higher than the capillary length of water.

1. Introduction

Liquid marble (LM) is an encapsulated system in which hydrophobic solid particles adsorbed to the droplet surface[1)]. Studies have been mainly conducted using water as an internal liquid of the LM. The capillary length of water is approximately 2.7 mm, and droplets with heights higher than this length are more affected by gravity than surface tension. Therefore, the LM shape deviates from (near)sphere to oblate, when the droplet volume is increased. Recently, we reported that LMs with polyhedral structures can be fabricated using millimeter-sized poly(ethylene terephthalate) (PET) plates as a stabilizer[2,3)]. The heights of the LMs fabricated so far are approximately 3-4 mm, which are close to the capillary length of water. Here, an interesting question is raised: how high and wide LM can be fabricated? In this study, we investigated how high and wide LM can be fabricated using millimeter-sized PET plates.

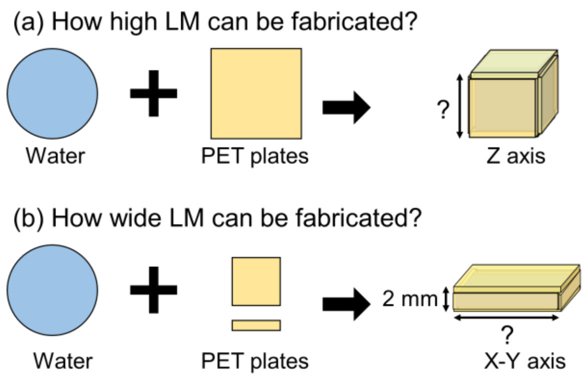

Fig. 1 Questions in this study: (a) how high LM can be fabricated? (b) how wide LM can be fabricated?

2. Experiment

The surface of PET plates (square, equilateral triangle, rectangle) was hydrophobized using (1H,1H,2H,2H-heptadecafuluorodecyl)trichlorosilane as a surface modifier in *n*-hexane medium. LMs were fabricated by adsorbing PET plates on water droplets (5 or 6 PET plates per one droplet). The hydrostatic pressure (P) applied to the PET plate at the bottom of the LM was estimated from Equation 1.

$$P = V \rho g / S \qquad \text{(Equation 1)}$$

V: volume of internal liquid, ρ: density of internal liquid, *g*: acceleration of gravity, *S*: area of PET plate at the bottom

3. Results and discussion

3.1 How high?

Cubic LMs with heights up to 5 mm were successfully fabricated (Fig. 2a). However, in the case of LMs with heights of ≥ 6 mm, the internal water leaked out from the bottom of the LM. In order to fabricate higher LMs, a particle-stabilized bubble with a volume of 5 μL was introduced into the LM, which reduces the apparent density of the internal liquid. As a result, cubic LMs with heights up to 6 mm could be fabricated (Fig. 2b). The hydrostatic pressure on the bottom PET plate decreased from 58.7 Pa to 56.0 Pa by the introduction of bubble. In addition, we attempted to fabricate an LM with an even lower hydrostatic pressure by changing the shape of the LM from a cube to a pyramid. As a result, pyramidal LMs with heights up to 7.9 mm were successfully fabricated (Fig. 2c). Furthermore, by introducing particle-stabilized bubble into the pyramidal LM, LMs with heights up to 9.8 mm could be fabricated (Fig. 2d). These results indicated that the introduction of bubble and shape change of the LMs, as well as their combination, can lead to fabrication of LMs with heights that greatly exceed the capillary length of water.

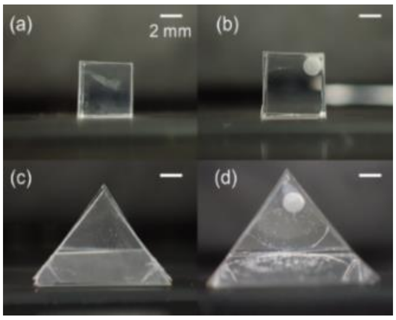

Fig. 2 Digital photographs of LMs stabilized with PET plates: (a) cubic LM (5 mm-sized PET plates), (b) cubic LM containing particle-stabilized bubble (6 mm-sized PET plates), (c) pyramidal LM (12 mm-sized PET plate), (d) pyramidal LM containing particle-stabilized bubble (14 mm-sized PET plate).

3.2 How wide?

Rectangular LMs were fabricated by adsorbing 6 PET plates, as a stabilizer, to the droplet surfaces using tweezers or fingers. As a result, the LMs with a height of 2 mm and widths from 5 to 1000 mm were successfully fabricated (Fig. 3).

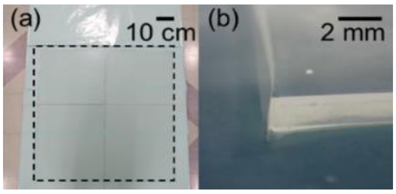

Fig. 3 (a) Digital photograph of 1 m-sized LM stabilized with 6 PET plates. (b) Magnified image of corner of the LM.

4. Conclusions

Introducing particle-stabilized bubble into the LM, changing the shape of the LM, and combining these two methods, it was possible to fabricate LMs with heights that greatly exceed the capillary length of the internal liquid. Additionally, it is expected that the width of LM is unlimited if the height does not exceed the capillary length of internal liquid.

References

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